Linking GIS and Crop Modeling to expect sorghum cultivars diffusion area in Mali

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Abstract

After drynesses of the years 1970 and 1980, important means were deployed to create adapted cultivars to shorter rain season. The diffusion of these cultivars knew little success because unsuited to the interannual variability of the climate and the strategies deployed by farmers to take account it.

The soudano-salian climate is characterized by an unimodale rain season whose beginning and end are extremely variable one year on the other. The frequential analysis of rain season structure with the Soil Balance Water model makes it possible to determine the beginning date and the completion date of season. Seventy rainfall stations distributed on the whole of the zone of rain agriculture of Mali were used.

The photoperiodism of local varieties allows the plant to naturally adjust the duration of its cycle at the probable duration of rain season. A simplified Crop Growth model of photoperiodism sorghums allows expecting the date of flowering of some cultivars representative of the zone of rain agriculture. A cultivars is considerate adapted to an ecology if its flowering occurs in the 20 days which precede the completion date of rain season.

The coupling of both models (Soil water Balance and of Crop Growth of the photoperiodic sorghums) within a Geographical Information System makes it possible to delimit for each cultivar its optimal zone of adaptation.

The obtained maps represent a synthesis useful tool for the agronomists who wish to determine a possible diffusion area of cultivars. This result also allows the breeders to improve the definition of the adapted "ideal" cultivars and makes it possible to envisage deserting the concept of broad geographical adaptation by the search for specific adaptations to each ecology.

Key words: Modeling, Agro-ecology, crop adaptation and photoperiodism

1 Introduction

The local millets and sorghums constitute the essence of the cereal production in Mali with 2 millions of tons in 2001-2002. The traditional systems have, until now, summer able to ensure the satisfaction of the food needs for the country. The population growth will involve a very keen food demand in the medium term. Until now the increase of the cereal production results especially from a strong extension of cultivated surfaces. The progressive saturation of the rural areas will make necessary to change the strategies and to intensify agricultural techniques.

For the plants of "short days" like sorghum, the flowering initiation takes place when the duration of the day goes down below a critical threshold (Heller, 1985). The photoperiodism of the African sorghums causes a reduction in the duration of the cycle when the date of sowing is delayed, thus ensures the synchronization of flowering with the end of the rain season. This characteristic is essential because the output and the quality of the grain depend closely on the date of flowering. The moulds and the insects or soup deteriorates the grain of the cultivars, which flower too precociously, by the birds. The cultivars, which flower too tardily, exhaust the soil water reserve before the filling of the grains is not finished (Kassam and Andrews 1975, Franquin 1984, Vaksmann and Al, 1996).

From the years 1960, to try to make more productive African cereals, the elimination of the sensitivity to the duration of the day was an essential objective of the of cereals improvement programs. The drynesses of the years 1970 consolidated scientists in this direction. The elimination of photoperiodism became also a need to lead to an early material able to support shorter rain seasons.

With the time passing, one realizes that this step did not attain its goals. The diffusion of the new cultivars is very limited and its performances are still in side those of the local cultivars (Lambert, 1983; Matlon, 1985).

The failure of the diffusion of modern cultivars of sorghum is explained mainly by the weak taking into account of the climatic constraints of the region, the strategies deployed by the farmers to hold account of it and of the specific qualities of local cultivars (Vaksmann and Al, 1998).

The existence of a strong interaction genotype X environment complicates the work of the agronomists who are condemned to experimentation on multiple sites over several years. To take into account this interaction, the Crop Growth Model allows envisaging the behavior of the varieties according to the environment.

The objective of this work is to show how to envisage the diffusion area of the photoperiodic varieties of sorghum by holding account of the climatic constraints, the varieties and the cropping systems with simple and effective tools.

2 Materials and Methods

2.1-Rain season characterization.

We use 70 rainfall stations (fig.4) selected according to the data availability from 1969 to 1998 for at least 27 years. The characterization of the rain season is carried out using the Soil Water Balance model BIPODE (Forest, 1986; Tuatara and Al, 1997). This model calculates the evolution of the water stock in soil with a step of daily time.

Simulations of the Soil Water Balance were systematically done and the characteristics parameters of rain season were evaluated by the method suggested by Traoré and al. (2000). It is mainly about beginning date and completion date of rain season defined as follows:

- the beginning date of season (BDS): it is the moment as from May 1 when soil water stock exceeds 30 mm without going down below 20 mm in the 20 days which follow;

- the completion date of season (CDS): it is the date from which rainfall do not compensate the evapotranspiration. This date generally corresponds to the filling of the grain of sorghums, which is done mainly with the free water stock in the soil.

2.2-Cultivars.

The studied varieties are CSM63E, CSM 219, CSM 388 and Gagna Ounlé. They come from the prospections carried out in Mali in years 1978 and 1996 and are representative of various ecologies of the rain agriculture region of the country. These varieties are of the botanical type *Guinean* most frequent in Mali. In each climatic zone we meet three types of cultivars (Ouattara and Al, 1998): early varieties,

varieties of season suitable for the region and late varieties. The early varieties contribute to face the welding period (the welding corresponds to a period of rupture of food stocks between two cropping years). The varieties of season occupy the greatest place and contribute essentially of the production. The late varieties correspond either to the development of particular situations (hollows) or with old varieties preserved by tradition often for cultural rites.

2.3-Photoperiodism Measurement.

The varieties were characterized at the agricultural research station of Sotuba (7.9° Est. and 12.7 North). In period of normal sowing (from May to July), there exists, for the photoperiodic sorghums, a linear relationship between the duration of vegetative period and the date of sowing (Traoré Al, 2000). Tests comprising several dates of sowing made it possible to establish this relationship for the 4 studied varieties. The slope of the straight line defined expresses the rate of photoperiodism of the cultivar in question and express the shortening of the duration of the cycle per day of delay of sowing.

Models more finely describing the mechanisms of photoperiodism were developed (Clerget and Al, 2004; Folliard and Al, 2004). However these models are very demanding; to function they require complete climatic data and a fine knowledge of the behavior of the plant according to the duration of the day. Consequently these models are very difficult to use and bring only one illusory precision for the realization of agro climatic zonings.

2.4-Cultivar's adaptation estimate.

It is generally considered the varieties adapted when they flower on average 20 days before the completion date of rain season (Ouattara and Al, 1998). We can define an adaptation index (I) by the difference between the completion date of season (CDS) and the date to flowering (DF):

$$I = CDS - DF \tag{1}$$

The index takes the zero value if the date of flowering of the variety and the completion date of season coincide. The optimal index is equal 10. If the index is lower than 0, the variety is too late and, reciprocally, an index superior than 20 characterizes a too early variety. For this study, one considers a variety is adapted to an ecology when the index (I) ranging between 0 and 20 (Fig.1).

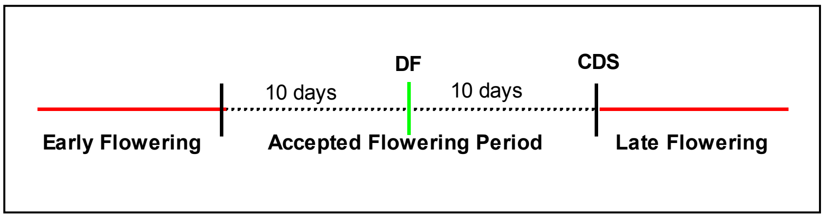

Fig.1. Adapatation Index estimation DF = Date of Flowering, CDS = Completion Date of Season

2.5-Adaptation area delimitation.

For each pluviometric site, the adaptation index (I) of each variety is calculated for the every years of the period 1969-1998. The average of index is calculated and extrapolated by Kriging The maps which result by it are integrated into the Geographical Information System (GIS) to determine the zones of adaptation of each variety.

3 Results

3.1-Rain season characterization : beginning date, completion date and Length Growth Period (LGP)

The structure of the season is marked by a strong space and interannual variability. But the proportion of variability is not the same one in space or time. The installation of the season is gradually made south towards the north from May 20 to July 10 on average. Howether the end of the season begins north towards the south on average from September 05 to October 06. The duration (LGP) follows a regressive gradient of the south towards the going north from 140 to 60 days. More one moves towards north more the duration of the season is short. Total pluviometry follows the same movement from 1400 mm in the south to 400 mm at the north. The speed and the relative stability of the completion date are related to the movement of the Intertropical Front whose descent is increasingly faster than his rise. The Intertropical Front expresses the position of the wet draughts blowing from ocean towards the grounds.

On the same site, the beginning date of the season is much more variable than the completion date. They are two independent events. It results from a strict relationship between the beginning date and length growth period (LGP). In other words more the season starts tardily more it is short.

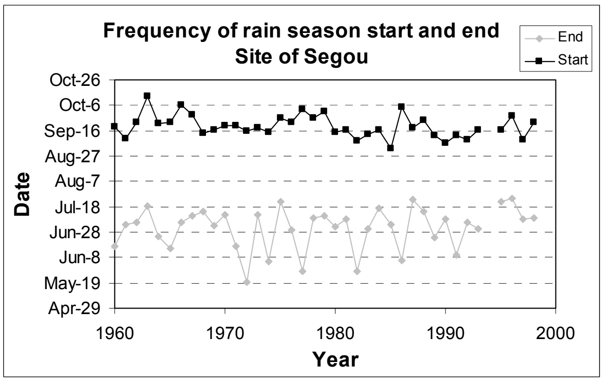

Fig.2 : Rain season beginning and completion dates at Ségou

On Ségou's site in sahelian zone (fig.2) over the period 1969-1998, the average duration of the season is 90 days but it varies from 80 (minimum) at 140 days (maximum). The date of beginning is much more unstable with a gap of 66 days howether the difference between the completion dates is 40 days. The beginning date is more variable but this variability evolved little in time. It results from this that the dryness probably marked the quantities of water fallen during the period of the strong rains than the structure of the rain season.

From one year to another, the length growth period of season is very variable. This strong interannual variability has a great influence on the adaptation of the cropping cycles to the structure of the season. The photoperiodism of the sorghum makes it possible to hold account of this interannual variability because it causes a reduction of the duration of the cycle when sowing is delayed and extension of the cycle when sowing is early. The adapted variety must be able to support at the same time the extension and the shortening of the duration of the season from one year to another.

3.2-The cultivars.

All studied cultivars are photoperiodic. In period of normal sowing (from May to July), there is a linear relation between the duration of the vegetative period and the date of sowing. The slope of the straight line resulting from this relation expresses the rate of photoperiodism of the cultivars in question. For example a slope of 0.5 means that delay of 10 days sowing involves a shortening of 5 days the vegetative period. A no photoperiodic variety will thus have a coefficient equal to 0 and one strict photoperiodic variety will have a coefficient equal to 1..

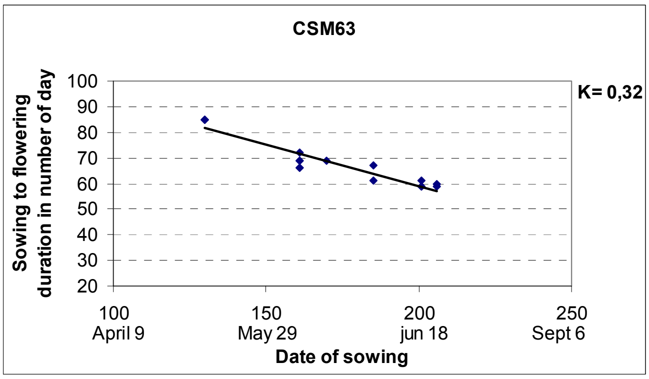

Fig.3: Sowing-flowering period duration (or vegetative phase variability) according the sowing date of the cultivars CSM63 at Sotuba agronomic station.

For variety CMS63, the duration of the cycle (the period sowing-flowering) varies from 60 to 85 days in Sotuba according to the dates of sowing (fig.3). The rate of photoperiodism expressed by the coefficient of correlation K = 0.32 means that delay of 10 days of sowing CSM63 leads 3 days shortening of the cycle. Thus any delay of date of sowing results in a shortening length of the cycle. CMS63 is a variety slightly photoperiodic.

Table.1 : Distribution of varieties according to the rate of photoperiodism and the average of the sowing-flowering period duration on the sites of adaptation.

Cultivars	Photoperiodism rate	Average duration of Sowing-flowering period
CSM63	0.32	63
CSM219	0.68	90
CSM388	0.75	111
Gagna Ounle	0.73	126

The rate of photoperiodism of the studied varieties varies from 0.75 to 0.3 (tab.1) from south to north. More the cycle is short minus the variety is photoperiodic. One notes an increase in the sowing-flowering duration for the varieties while moving towards north from 126 days for Gagnan Ounle to 63 days for CSM63.

3.3-The zones of adaptation.

Variety CSM63 is regarded as a very early variety in Mali. It appears theoretically adapted to the areas of which the length of the season is higher or equal to the length of the cycle (63 days).

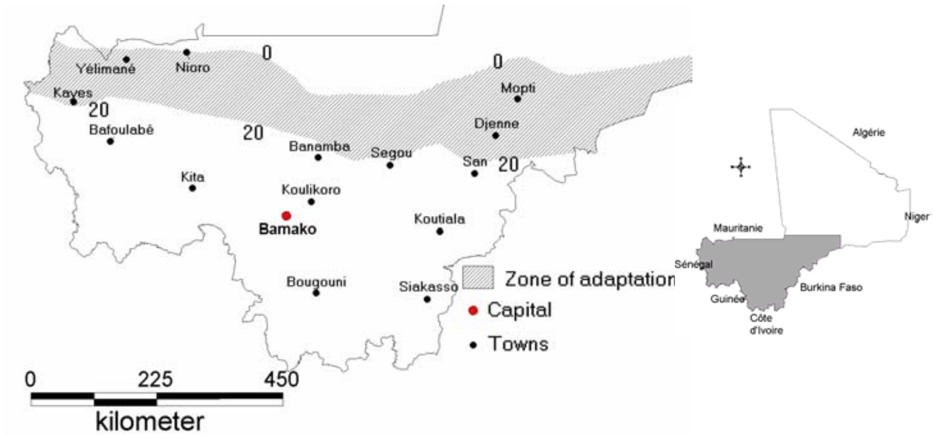

Fig.3: Optimal adaptation zone of the cultivar's CSM63. It is about the zone, for which flowering takes place on average in the 20 days which precede the end by the rain season.

The sowing-flowering duration of CSM63 on the sites to which it is adapted varies from 60 days to 66 days with average of 63 days. CMS63 is not a very photoperiodic variety (k=0.3). Considering its weak sensitivity with photoperiod, it offers little flexibility for the choice of the sowing date. Its area of adaptation is located more at north in sahelian zone with a pluviometric lower than 700 mm (fig.3), which delimits a band of approximately 200 km. It adapts to the cropping systems of this agricultural area mainly based on the millets and sorghums.

According to the logic to search varieties of short cycle, CSM63 should adapt to areas of which the duration of the rain season is higher or equal to 63 days, therefore to be able to be diffused in all the country. But, apart from its zone of adaptation (fig. 3), the chances of success of CSM63 are null. Its cycle is too short to adapt to one longer rain season. Sowing at the beginning of season results in a too early flowering which compromises the chances of harvests seriously. Late sowing to fix its cycle on the structure of the season is not possible. Late sowings give weak outputs for many reasons: compete between crop and the adventitious, acidification of soil after the beginning of the rains, scrubbing of nitrogen, excess of moisture etc.

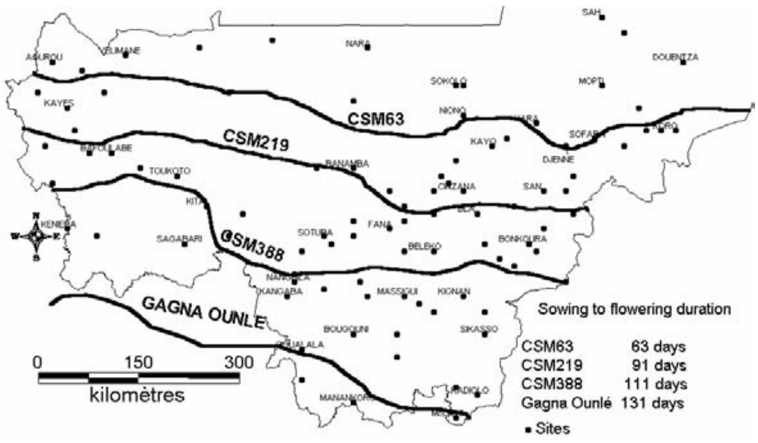

Fig.4: Passage of the optimal adaptation index of the four varieties. The index (I) is equal 10, which corresponds to the optimum.

In accordance with the characteristics of the rain season, the varieties adaptation zones follow a distribution of the south towards north according to the length of the cycle sowing-flowering (tab.2) and (fig..4). Varieties CSM219, CSM388 and Gagna Ounlé are adapted to soudanian and Guinean zones on the agricultural regions of the Mali-South, the Center and the West (fig.4). The photoperiodic character (K >0.7) of these varieties allows their adaptation to the structure of the season but also to the constraints of calendar of the farming systems. The photoperiodic variety offers a great flexibility in the choice of the sowing date.

The sorghum occupies a weak place in the rotation in these areas. It is associated to maize and cotton, which are the priority crops for the farmers. It is sown only after the intensified cultures (cotton and maize) and on marginal soils. The flexibility of the sowing date contributes much to maintain and develop the cropping of sorghum in the southern agricultural areas of the country. The 2004 agricultural season knew a very difficult beginning following the late installation of the rains. After several sowings, the cotton and cornfields badly germinated. On the fields which failed maize and cotton were systematically replaced by the sorghum (Square, 2004).

No variety has a broad geographical adaptation, which would justify its diffusion with all the country. Each variety is adapted on average on a tape of 200 km width of north to the south. This result explains well the failure of the diffusion of the modern fixed cycles varieties created by the breeding programs.

4 Discussions et conclusion

For the photoperiodic sorghums, the interactions genotype X environment are important and do not allow to simply envisage the future of a variety subjected to the environmental constraints of soudano-sahelian climate

Face this difficulty to take into account at the same time the cultivars and an environment particularly variable, the agronomists are brought to reason on cultivars of duration of fixed cycle adapted to one average rain season, which really does not exist. This step showed its limits, the modern varieties do not adapt to the climatic constraints. In spite of their high potential yield, their productivity remains low. After 50 years of varietal improvement, the local photoperiodic cultivars produce as much, if not more, than the early varieties of research under the same conditions of cropping (Luce, 1994). The early varieties, which had, for the researchers, a broad geographical adaptation are generally confined at the sahelian zone (pluviometry 600 mm) and are unable to succeed more in the south in land more wet.

The coupling of soil balance water model and a simplified crop growth model of the photoperiodic sorghums within a Geographical Information System makes it possible to facilitate the understanding of complex mechanisms and to delimit for each variety the optimal zones of adaptation.

In accordance with the characteristics of the rain season, the varieties follow a distribution of the south towards north according to their degree of photoperiodism. Each variety has a relatively narrow zone of adaptation, on average on a tape of 200 km of width of north in the south, and it is unusual to find them outwards.

Variety CSM63 is regarded as a very early variety in Mali. It appears theoretically adapted to the areas of which the length of the season is higher or equal to the length of the cycle (63 days).

The obtained maps represent a useful tool for synthesis for the agronomists who wish to determine the possible zone of diffusion of cultivars by holding account of his chances of success. They make it possible to spatially extrapolate results obtained with the fields and often limited in time.

This result also makes it possible for breeders to improve the definition of the ideal cultivars adapted and makes it possible to plan to give up the concept of broad geographical adaptation by the search for specific adaptations to each ecology. At the time of a strategic choice of parietal creation, the real challenge consists in finding productive varieties, adapted, sensible to photoperiodism, the temporal variability of the climate for a specific site.

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